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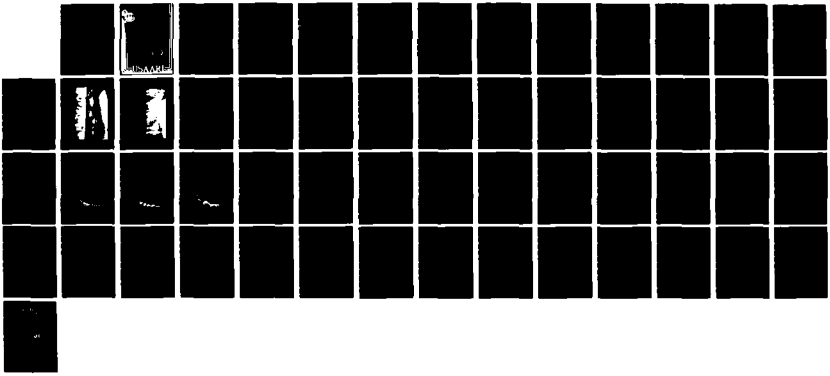

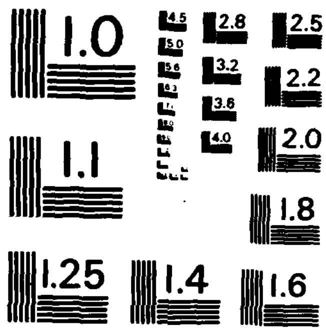

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DIRECT DETERMINATION OF THE ADEQUACY OF HEARING PROTECTIVE DEVICES FOR USE WITH THE M198, 155mm TOWED HOWITZER

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Human subjects participated in these studies after giving free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 70-25 on Use of Volunteers in Research.

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ABSTRACT:

The peak sound pressure levels of the M198, 155mm howitzer firing the M203 propelling charge are far in excess of the exposure limits set forth in the Army hearing conservation criteria. The levels are of a sufficient magnitude that there is serious question whether adequate hearing protection is available. This study provides direct evidence for the adequacy of the E-A-R earplug to protect against the impulse noise of the M198/M203. Fifty-nine volunteers were exposed to a progression of impulse noise levels produced by the M198 and tested for temporary threshold shift. It was found that the threshold shift exhibited by 95 percent of the volunteers was within acceptable limits after exposure to 12 rounds of M203 charge. This finding is interpreted to mean that these earplugs provide adequate hearing protection. In addition, volunteers were evaluated for evidence of laryngeal injury and intestinal injury. None was found.

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SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Late in the development cycle of the M198, 155mm howitzer, it came to the attention of the Army Surgeon General's Office that the impulse noise levels produced by the weapon were excessive. The peak sound pressure levels for the M198 firing the M203 charge are as high as 182 dB in crew-occupied areas (Patterson, Mozo, 1978). These levels are far in excess of the National Research Council's Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), impulse noise damage risk criterion published in 1968 and the Army hearing conservation criterion set forth in TB-MED-501. The M198/M203 also exceeds all noise limits for Army materiel as defined in MIL-STD-1474B(MI). The impulse noise is of such magnitude that the question is raised whether any available hearing protective device affords adequate protection for the hearing of personnel operating the weapon. This consideration led the Army Surgeon General to recommend severely limiting the exposure of personnel to the impulse noise produced during firing of the M203 charge pending a determination of what constitutes adequate hearing conservation measures.

Adequate hearing protection for the M198 can be defined as that which will limit the Temporary Threshold Shift (TTS) resulting from 12 rounds of Zone 8 firing in sustained fire mode (one round per minute) to the levels in Table 1 for 95 percent of the exposed population. This definition is derived from the CHABA (1968) definition for an acceptable exposure in formulating their damage risk criterion for impulse noise and from doctrinally specified maximum number of M203 rounds to be fired in a 24-hour training period.

In order for operational training with the M198/M203 to continue without undue hazard to the firing crews, it was necessary to validate the adequacy of available hearing protective devices to attenuate the impulse noise to a nonhazardous level. The hearing protective devices selected to be evaluated were E-A-R* earplugs used separately and in combination with the Gentex* model DH-178 helmet. The E-A-R earplugs are the most efficient sound attenuators of all the plugs currently in the National Stock System (Camp <u>et al</u>., 1972 and Nelson <u>et al</u>., 1977). The DH-178 is a nonstandard helmet similar to the standard Combat Vehicle Crewmen (CVC) helmet manufactured by Gentex. It features a ballistic protective outer shell and an active "talk-through" circuit which limits high-level sounds and permits low-level sound to be passed into the sound attenuating earcups via earphones. The DH-178 helmet was selected because it meets the requirements of The Surgeon General for good circumaural hearing protection while meeting the requirements of the artillerymen for ballistic helmet protection and "talk-through" capability (Patterson <u>et al</u>., 1978). The primary objective of the study was to determine whether in fact the E-A-R earplug alone or in combination with the DH-178 helmet does provide the required protection.

The basic procedure was to estimate the amount of TTS produced by relatively safe levels of impulse noise for a sample of subjects wearing protection, and then to increase the exposure level in steps approaching the

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*See Appendix D

maximum exposure of 12 impulses at the maximum level. After each exposure, a determination was made as to whether the protection was adequate before proceeding to the next higher level.

TABLE 1

MAXIMUM ALLOWABLE TTS FOR 95 PERCENT OF EXPOSED POPULATION

Frequency (Hz)	Max TTS in dB
500	10
1000	10
2000	15
3000	20
4000	20
6000	20
8000	20

It is generally believed that sounds which produce small TTSs which recover rapidly are not producing any significant permanent hearing losses (Henderson et al., 1976). There is ample evidence in the literature to demonstrate that small TTSs (less than 35 dB) can be induced occasionally without any long-term (permanent) elevation of the subject's threshold (e.g., Ward, Selters, and Glorig, 1961; Ward, 1962; Hodge and McCommon, 1966). The starting exposures in this experiment were calculated to assure that no subject would suffer a large TTS. This procedure provided for the safety of the subjects by cautiously approaching the maximum exposure.

Intense blast overpressure can also damage nonauditory organ systems, specifically, such air-containing organs as the lungs, the nasal sinuses, and the gastrointestinal tract (White et al., 1971 and Chiffelle, 1966). In nuclear level blast, it is the pulmonary parenchyma where injury is most evident and contributes most to morbidity and mortality. However, studies conducted by Walter Reed Army Institute of Research (WRAIR) and the Lovelace Inhalation Toxicology Research Institute (LITRI) have shown no evidence of classic blast-type hemorrhagic injury with repeated low level (<100 kPa) blast (Yelverton et al., 1983). The trachea and major bronchi are another part of the respiratory system where blast injury has been observed. Grossly, the trachea shows petechiae or small hemorrhages. Their incidence roughly parallels that of laryngeal damage, with the trachea generally showing a milder degree of injury. Laryngeal petechiae or small hematomas are an almost universal finding in animals exposed to significant numbers of and/or intensity of blast. These petechial lesions are benign and would cause little if any discomfort. Stripping of epithelium from trachea or bronchi has previously been noted in nuclear level blast and more recently it has been produced by multiple lower level blasts. Pneumothorax is a pulmonary injury described rarely with nuclear level blast. One sheep in the highest exposure group experienced pneumothorax during the July 1980 Aberdeen Proving Ground, Maryland study. No others have been reported in these studies. Interestingly, during the summer of 1980, two gunners at Yuma Proving Ground, Arizona, suffered spontaneous pneumothoraces. An intense investigation revealed no clear blast association. This is important because stresses at the pleural surface in blast are likely to be greater than at any other parenchymal location and rupture of alveoli at the pleural surface might be expected to result in a pneumothorax. It is possible that the presence of pleural blebs or bullae (a congenital abnormality) could predispose to blast-induced pneumothorax.

In a single, nuclear level blast exposure, gastrointestinal (GI) injury is evident, but is overshadowed by the more dramatic injury to the lungs. However, with some combinations of multiple shot, lower level blast exposure, the GI tract shows the greater degree of injury (Clifford, et al., in press). The lesions consist of bleeding into the wall of the gut primarily in the stomach (rumen in sheep) and large intestine. They range in severity from petechiae or slight hemorrhage to large hematomas that involve the full thickness of the bowel wall. Studies with underwater blast have suggested that the amount of gas in a segment of bowel has some effect on the degree of injury (Fletcher, E. R., Yelverton, J. T., and Richmond, D. R., 1976). Pigs have stomachs similar to man's, and LITRI has demonstrated similar, but less dramatic blast related hemorrhagic lesions in the stomachs of swine. A report of GI injury in humans from an underwater explosion indicated severe large intestinal injury with no mentionable gastric damage (Huller and Bazini, 1970).

METHODS AND MATERIALS

AUDIOMETRIC MEASUREMENTS

Standard clinical audiograms were obtained for subject selection using the manual method. A Grason-Stadler* audiometer at Kirk Army Health Clinic, Aberdeen Proving Ground, Maryland, was used for this purpose.

Audiograms used for estimating threshold shift were determined on the firing range using a multichannel microprocessor audiometer developed specifically for this study. Details of this audiometer were described by Mozo, et al., 1984. Briefly, it uses a fixed frequency tracking procedure to determine thresholds. The order of testing various frequencies was 2.0, 4.0, 6.0, 3.0, 8.0, 2.0, 1.0, and .5 kHz. Since 2.0 kHz was tested twice, the first test of this frequency was used as a "warm-up" test and not included in the data analysis. The remaining frequencies were ordered on the basis of likelihood to show an effect.

This audiometer was housed in the USAARL mobile audiometric facility which had been parked approximately 80 meters from the firing point (Figure 1 shows an overview of the test area.) The trailer has four individual double-walled test booths inside a large single-walled noise excluding room. Additional noise control during audiometric testing was accomplished by use of noise excluding headsets which are part of the audiometer.

Before any noise exposure, each subject was instructed in the procedures for tracking an audiogram and given four practice audiograms. These were checked for consistency of tracking and threshold. They were not used in any of the data which follows.

On each exposure day, two audiograms were obtained on each volunteer before the noise exposure. These were averaged to provide his preexposure audiogram for that day. After each exposure, audiograms were obtained starting at 2, 20, and 60 minutes after the exposure (audiograms were to be obtained at longer postexposure time intervals if any TTS remained). The primary Threshold Shift (TS) data were calculated by subtracting the preexposure audiogram for that day from each of the postexposure audiograms.

After all exposures had been completed, a second clinical audiogram was obtained in the Kirk Army Health Clinic using the manual method.

NONAUDITORY MONITORING

Before the first and after the last noise exposure, a trained otolaryngologist performed an indirect laryngoscopy on each volunteer. A chest roentgenogram and a forced expiratory spirometry test were obtained before the series of exposures, and the roentgenogram was repeated at full exhalation after noise exposure. During the study, stool samples from the volunteers were tested for blood by the quaiac reaction. The samples were self-collected; therefore, they were not obtained daily by all volunteers.

ACOUSTIC MEASUREMENTS

Preliminary calibration of the sound field was accomplished by firing each charge with no volunteers present. These data were analyzed and final locations where volunteers would be exposed were determined based on these calibration results.

All acoustic measurements were obtained in accordance with guidelines established by The Working Group for Standardization of Muzzle Blast Overpressure Measurements under the Ad Hoc Subgroup for Blast Overpressure of the Army Science Board (Patterson et al., 1980).

Four gauges were used to monitor subject exposures and one ground plane reference gauge was used. Figure 2 shows the location of all measurement gauges and the volunteer locations. The subject gauges were blunt-mounted

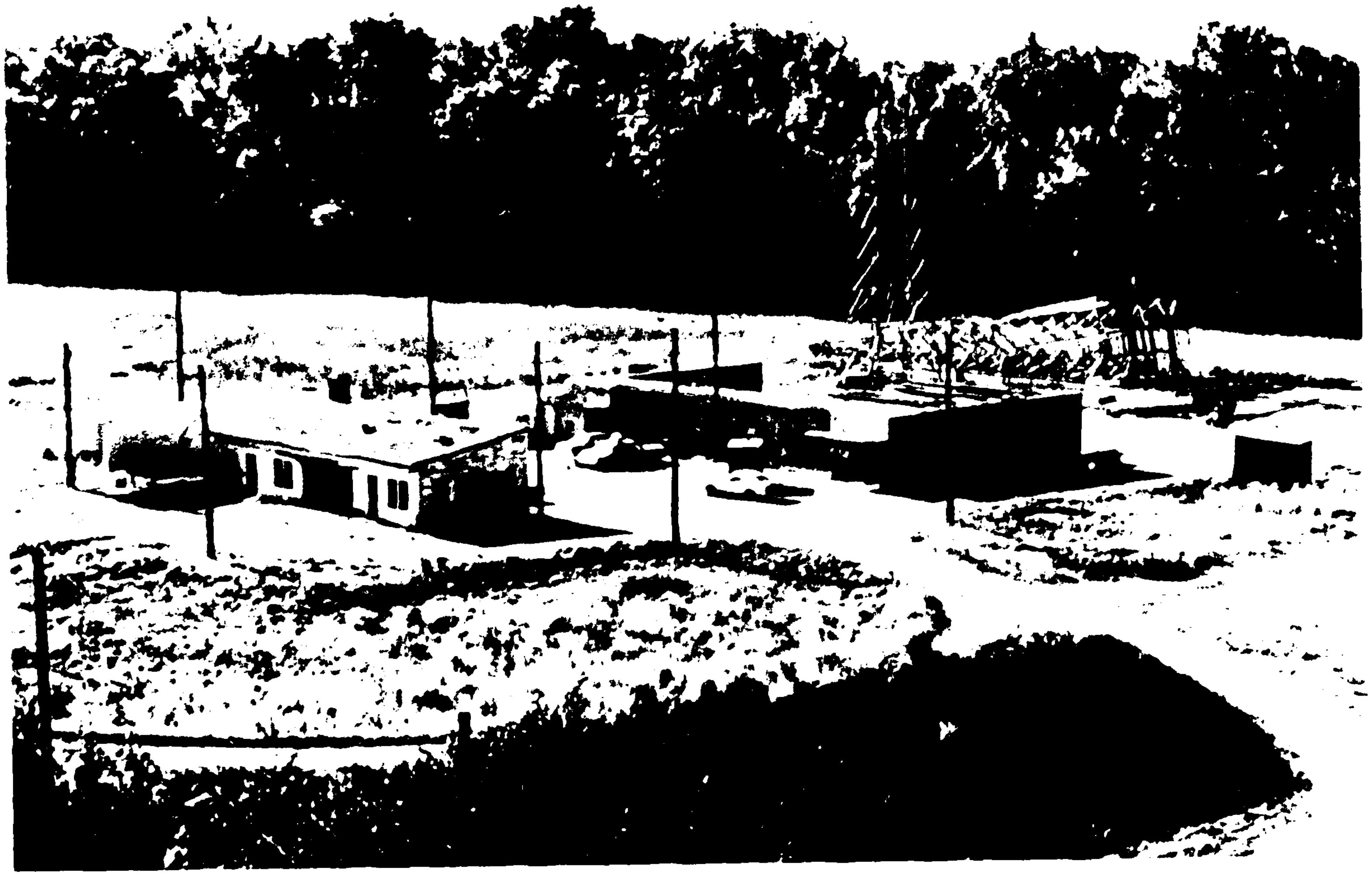

FIGURE 1. Overview of Test Area.

FIGURE 2. Location of Volunteers and Measurement Gauges Around M198, 155mm Howitzer.

at grazing incidence to the muzzle, 5 feet above the ground. Two gauges were positioned on each side of the cannon. Table 2 shows the distances of the four gauges from the muzzle and the breech. These positions bracket the subject locations on each side of the weapon.

TABLE 2

LOCATION OF BLAST MEASUREMENT GAUGES

	Gauge Location			
	1	2	3	4
Distance from Muzzle	21' 9"	21' 3"	21' 5"	21' 7"
Distance from Breech	6' 8"	3' 6"	3' 2"	6' 7"

The data were obtained using the EG&G* high speed data acquisition system. The high speed data acquisition system provides direct analog-to-digital conversion at 250,000 samples per second on each channel. These digital signals are stored on tape for later analysis. In addition, analog recordings were made using a Sangamo* Sabre VI FM recorder with wide band group I electronics. This provided backup and alternative analysis capability.

The time histories of selected samples of blast waves recorded during the exposures were analyzed for several parameters which are contained in national standards or under consideration for potential use in national or international standards which limit exposure to impulse noise. These parameters include: Peak pressure, A-duration (CHABA 1968), B-duration (MIL-STD-1474B), D-duration (Smoorenburg, 1982), C-duration (Pfander, Bongartz, and Brinkmann, 1975), total energy per unit area, and A-weighted energy per unit area (Appendix A contains the formulas for these energy measures.)

VOLUNTEERS

A total of 60 male volunteers completed the entire sequence of exposures. All were military personnel with less than 5 years service. Of these, only 59 provided a complete set of data. One individual was dropped from the analysis because he reported nausea and vertigo upon entering the audiometric trailer after the M203 firing. His initial postexposure audiogram was aberrant, showing a failure to track the test tones. After 20 minutes he felt better and his 20-minute audiogram was normal as were all other audiograms including the clinical posttest. These volunteers were clustered in groups of four since four audiograms could be obtained simultaneously. (Because of dropouts, some groups ended up with less than four.)

The volunteers were selected from the US Army Ordnance School and Material Test Directorate at Aberdeen Proving Ground, MD, Walter Reed Army Institute of Research, Washington, DC, US Army Medical Research Institute of Infectious Diseases, Fort Detrick, MD, US Army Aeromedical Research Laboratory, Fort Rucker, AL, and US Army Aeromedical Center, Fort Rucker, AL.

Volunteers selected had audiometric thresholds better than +10 dB HL (American National Standards Institute (ANSI) 1969) for frequencies .5 and 1.0 kHz and better than +20 dB HL for frequencies from 2.0 through 8.0 kHz. In addition, they were selected for normal preexposure chest X-ray, spirometry, laryngoscopic examinations, and negative stool guaiac.

TEST SCHEDULE

Each group of four subjects followed the same schedule for 6 days of participation. Table 3 lists the activities for each day of the week. Several groups of four volunteers participated in each week's activities. The entire test required 5 consecutive weeks to run 60 subjects.

MISCELLANEOUS PROCEDURES

Twelve rounds were fired for each charge, paced at one per minute. The cannon was fired at 0 mils azimuth and 60 mils quadrant elevation using M102 projectiles inertly loaded to 102 pounds. The volunteers were oriented so that their right ears were toward the muzzle. Prior to each exposure, the volunteers inserted their own earplugs (E-A-R*). The experimenter visually inspected all earplugs for proper insertion depth and good fit. The Personnel Armor System for Ground Troops (PASGT) infantry helmet was worn for ballistic protection (no hearing protection included when only earplugs were worn).

The research plan called for the use of earplugs alone until an exposure produced a TTS which exceeded any of the values in Table 4. If such a TTS occurred, then on the succeeding day the exposure would not be increased, rather it would be repeated with the volunteer wearing a DH-178 helmet as an added hearing protector. This volunteer would then use double hearing protection for the remainder of the test. Following each exposure, the volunteers were restricted to nonnoisy duty and instructed to avoid additional noise exposure.

PRETEST OF DH-178 HELMETS

In preparation for use in this study 10 DH-178 helmets were tested in the laboratory in accordance with ANSI Standard Z24.22-1957, "USA Standard Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at

TABLE 3

TEST SCHEDULE FOR EACH GROUP OF VOLUNTEERS

Day	Activity
1 - Sunday	Audiometric and medical screening in the clinic
2 - Monday	Audiometric and procedural training on the range
3 - Tuesday	Exposure to M4A2, Zone 7, 12 rounds
4 - Wednesday	Exposure to M119, Zone 8, 12 rounds
5 - Thursday	Exposure to M203, Zone 8S, 12 rounds
6 - Friday	Audiometric and medical posttest in clinic

TABLE 4

MAXIMUM ALLOWABLE TTS FOR AN INDIVIDUAL SUBJECT

Frequency (Hz)	Max TTS in dB
500	25
1000	25
2000	30
3000	35
4000	35
6000	35
8000	35

Threshold." These tests were performed to provide a data base for the quality of each DH-178 so that helmets with attenuation characteristics as similar as possible could be used and to assure that a defective protector was not given to a volunteer to use. Details of this test methodology have been described elsewhere (Patterson et al., 1978).

STATISTICAL CONSIDERATIONS

The hearing protector attenuation and acoustical measurement data were analyzed using standard descriptive statistics, e.g., mean and standard deviation. The threshold shift data were analyzed for mean and standard deviation and the 95 percent confidence bound on the 95th percentile TS was estimated using order statistics (Hogg and Craig, 1965) (see Appendix B).

RESULTS AND DISCUSSION

The attenuation characteristics of the 10 DH-178 helmets are summarized in Table 5 as mean and standard deviation values.

Table 6 contains the physical acoustic data obtained during the calibration rounds fired with no volunteers present. These results indicated the progression of increasing exposure levels produced by the series of propelling charges (M4A2, M119A2, M203) was acceptable to assure the safety of the volunteers.

Typical pressure-time histories and Fourier pressure spectra for each propelling charge are shown in Figures 3 through 8. The entire set of exposure rounds was analyzed for selected parameters in accordance with MIL-STD-1474B(MI). Tables 7, 8, and 9 summarize these parameters based on all exposure rounds for each charge. A subset of these rounds was selected arbitrarily for more extensive analysis. Tables 10, 11, and 12 summarize the parameters of impulse noise which are used in the various national standards. The total energy per unit area is included for comparison. These data are from a typical exposure set of 12 rounds.

Since the various national standards use the peak pressure and different measures of duration to assess the hazard of impulse noise, they can be compared most easily by calculating the number of rounds per day each would allow for the same blast data. Table 13 shows the allowable number of rounds computed according to the US MIL-STD-1474B(MI) (CHABA extrapolation), Pfander, Bongartz, and Brinkmann, (1975), and Smoorenburg (1982). Formulas for these calculations are in Appendix C. Since the US military standard has an assumption of 29 dB attenuation for single hearing protection built into it, the other procedures were calculated allowing both 29 dB and 25 dB. The latter is more commonly used in Germany and the Netherlands. These results indicate

TABLE 5

ATTENUATION CHARACTERISTICS OF 10 DH-178 HELMETS

Helmet		Test Frequencies in Hertz 75	125	250	500	1K	2K	3K	4K	6K	8K
Small A	Mean	19.8	19.2	21.3	25.0	32.2	23.7	37.9	44.3	35.5	31.7
	SD*	4.4	3.1	2.5	3.7	5.9	3.6	7.7	7.1	7.7	7.0
Small B	Mean	18.7	20.3	22.0	27.4	33.7	24.7	38.0	43.9	39.5	34.3
	SD	6.5	4.8	3.2	4.1	4.7	4.1	4.6	6.8	7.8	10.3
Medium C	Mean	19.7	21.0	22.7	27.7	32.5	29.3	34.2	46.2	40.8	34.5
	SD	5.5	4.4	3.0	3.0	4.7	3.2	3.9	5.5	4.7	5.5
Medium D	Mean	18.5	18.2	20.8	26.2	31.9	29.0	34.5	42.3	36.1	29.2
	SD	4.1	3.8	3.1	3.2	4.2	4.8	3.4	4.7	5.6	6.2
Medium E	Mean	16.6	18.3	21.4	26.6	34.9	28.3	34.5	44.5	36.0	32.4
	SD	4.1	3.9	3.8	4.3	5.0	3.9	4.2	5.0	5.7	6.3
Medium F	Mean	15.9	17.8	20.9	26.1	32.1	24.1	35.2	43.0	33.9	33.4
	SD	4.9	3.0	2.9	4.3	4.5	5.5	4.3	4.9	5.3	5.9
Medium G	Mean	17.5	20.6	21.5	26.2	29.0	26.8	35.9	44.0	37.4	33.5
	SD	4.4	5.6	3.4	2.5	3.3	5.4	5.2	4.2	6.1	6.0
Medium H	Mean	15.4	16.3	18.7	23.3	28.8	32.3	35.8	42.1	38.0	31.1
	SD	3.5	4.2	2.9	3.4	4.5	6.8	5.0	5.4	6.2	5.1
Large I	Mean	18.5	19.9	20.3	26.6	30.4	30.2	31.9	45.0	36.8	31.5
	SD	5.0	3.9	2.7	3.0	3.9	6.4	4.1	6.6	7.2	5.8
Large J	Mean	14.4	16.4	19.3	25.0	31.3	25.3	29.6	43.0	32.2	28.3
	SD	4.4	4.7	4.2	4.5	5.3	4.3	3.7	5.0	8.6	8.6

*Standard Deviation

TABLE 6

EXPOSURE CONDITIONS FOR M198

Charge	Zone	Peak	B-Duration	ANR*
M203	8S	180.7 dB	43.4 ms	1
M119A2	8	177.2 dB	33.6 ms	10
M4A2	7	173.4 dB	37.1 ms	49

*Allowable number of rounds per MIL-STD-1474B(MI)

TABLE 7

VALUES OF SELECTED PARAMETERS OF THE BLAST OVERPRESSURES PRODUCED BY THE M198 HOWITZER WHILE FIRING THE M4A2 CHARGE MEASURED AT THE SUBJECTS' LOCATIONS

		Gauge Location			
		1	2	3	4
Peak Pressure in dB, SPL	Mean	174.0	172.7	173.6	173.7
	SD*	1.0	.8	.7	.9
Peak Pressure in KPa	Mean	10.3	8.3	9.7	9.7
	SD	1.4	1.4	1.4	1.4
A-Duration in ms	Mean	5.2	5.4	4.8	4.8
	SD	.5	.3	.4	.3
B-Duration in ms	Mean	36.7	45.1	39.8	40.0
	SD	5.4	5.1	6.0	6.5
Number of Allowable Rounds**	Mean	42.0	56.9	44.3	41.3
	SD	18.1	18.7	12.8	14.0
Number of Measurements		155	154	155	155

*Standard Deviation

**MIL-STD-1474B(MI)

TABLE 8

VALUES OF SELECTED PARAMETERS OF THE BLAST OVERPRESSURES PRODUCED BY THE M198 HOWITZER WHILE FIRING THE M119A2 CHARGE MEASURED AT THE SUBJECTS' LOCATIONS

		Gauge Location 1	2	3	4
Peak Pressure in dB, SPL	Mean	177.9	176.4	177.3	178.3
	SD*	.9	.7	.6	.9
Peak Pressure in KPa	Mean	14.5	13.1	14.5	15.9
	SD	4.8	2.1	2.8	2.8
A-Duration in ms	Mean	5.6	5.5	4.9	5.1
	SD	.5	.3	.2	.2
B-Duration in ms	Mean	33.5	40.9	37.1	34.9
	SD	3.7	6.3	5.6	5.7
Number of Allowable Rounds**	Mean	7.8	11.5	8.7	6.1
	SD	2.7	3.8	2.4	2.1
Number of Measurements		175	186	187	187

*Standard Deviation

**MIL-STD-1474B(MI)

TABLE 9

VALUES OF SELECTED PARAMETERS OF THE BLAST OVERPRESSURES PRODUCED BY THE M198 HOWITZER WHILE FIRING THE M203 CHARGE MEASURED AT THE SUBJECTS' LOCATIONS

		Gauge Location 1	2	3	4
Peak Pressure in dB, SPL	Mean	180.7	180.2	180.3	181.8
	SD*	.8	.9	.6	.6
Peak Pressure in KPa	Mean	20.0	20.0	20.0	23.4
	SD	6.2	4.1	3.4	6.2
A-Duration in ms	Mean	5.7	5.1	4.5	5.0
	SD	.5	.4	.3	.3
B-Duration in ms	Mean	46.8	49.1	47.8	43.1
	SD	9.9	8.9	9.1	8.0
Number of Allowable Rounds**	Mean	1.4	1.7	1.6	.95
	SD	.8	.9	.7	.5
Number of Measurements		175	186	187	181

*Standard Deviation

**MIL-STD-1474B(MI)

TABLE 10

VALUES OF PARAMETERS OF THE BLAST OVERPRESSURES PRODUCED BY THE M198 HOWITZER WHILE FIRING THE M4A2 CHARGES (SELECTED SUBSET) MEASURED AT THE SUBJECTS' LOCATIONS

		Gauge Location 1	2	3	4
Peak Pressure in dB, SPL	Mean	173.9	172.0	173.4	173.8
	SD*	.8	.4	.7	1.0
Peak Pressure in KPa	Mean	9.7	8.3	9.7	9.7
	SD	.7	.7	.7	1.4
A-Duration in ms	Mean	5.1	5.3	5.0	4.9
	SD	.2	.2	.4	.2
B-Duration in ms	Mean	33.6	44.6	42.4	38.2
	SD	2.3	3.6	7.6	6.7
C-Duration in ms	Mean	6.2	7.5	6.0	6.3
	SD	.7	.9	.7	.7
D-Duration in ms	Mean	13.3	19.9	16.9	16.6
	SD	2.0	2.6	2.5	3.6
A-Impulse** in Pa-s	Mean	29.0	27.6	26.2	26.9
	SD	1.4	1.4	2.1	.7
Total Energy in *** joules/M^2	Mean	584.0	416.4	494.0	581.4
	SD	13.0	13.0	9.0	14.3
A-Weighted Energy*** in joules/$M^2$2	Mean	50.8	42.3	52.1	56.4
	SD	4.6	4.1	4.1	4.8
Number of Measurements		12	12	12	12

*Standard Deviation.

**A-Impulse is the area under the positive phase of the pressure-time history which includes the peak.

***See Appendix A.

TABLE 11

VALUES OF PARAMETERS OF THE BLAST OVERPRESSURES PRODUCED BY THE M198 HOWITZER WHILE FIRING THE M119A2 CHARGES (SELECTED SUBSET) MEASURED AT THE SUBJECTS' LOCATIONS

		Gauge Location 1	2	3	4
Peak Pressure in dB, SPL	Mean	178.8	175.8	177.6	178.6
	SD*	.8	.5	.7	.7
Peak Pressure in KPa	Mean	17.2	12.4	15.2	17.2
	SD	2.1	.7	1.4	1.4
A-Duration in ms	Mean	5.4	5.5	4.8	5.2
	SD	.3	.2	.1	.2
B-Duration in ms	Mean	30.1	37.9	34.3	33.9
	SD	2.8	7.6	2.3	5.3
C-Duration in ms	Mean	6.0	8.2	5.9	6.1
	SD	.8	.6	.6	.3
D-Duration in ms	Mean	12.2	19.7	16.1	11.8
	SD	1.3	3.5	2.9	1.5
A-Impulse in Pa-s	Mean	52.4	48.3	42.1	51.0
	SD	3.4	1.4	2.1	2.1
Number of Measurements		12	12	12	12
Total Energy in** joules/M^2	Mean	1199.5	1365.4	1368.9	1527.9
	SD	22.8	29.9	232.3	46.4
A-Weighted Energy** in joules/M^2	Mean	85.9	88.1	99.2	108.0
	SD	11.4	6.6	22.5	54.4
Number of Measurements		12	11	11	12

*Standard Deviation

**See Appendix A

TABLE 12

VALUES OF PARAMETERS OF THE BLAST OVERPRESSURES PRODUCED BY THE M198 HOWITZER WHILE FIRING THE M203 CHARGES (SELECTED SUBSET) MEASURED AT THE SUBJECTS' LOCATIONS

		Gauge Location 1	2	3	4
Peak Pressure in dB, SPL	Mean	181.0	180.1	180.1	181.9
	SD*	.6	.6	.5	.5
Peak Pressure in KPa	Mean	22.8	20.0	20.7	24.8
	SD	1.4	1.4	1.4	1.4
A-Duration in ms	Mean	5.8	5.5	4.6	5.0
	SD	.4	.3	.1	.1
B-Duration in ms	Mean	47.3	51.8	49.4	45.3
	SD	10.5	7.7	7.0	6.2
C-Duration in ms	Mean	4.2	5.3	4.3	3.5
	SD	1.4	.5	.7	.4
D-Duration in ms	Mean	11.3	16.3	12.0	7.3
	SD	8.5	7.2	6.4	5.1
A-Impulse in Pa-s	Mean	86.2	77.2	62.7	77.2
	SD	4.8	5.5	2.8	4.1
Number of Measurements		9	11	12	12
Total Energy in** joules/M^2	Mean	2480.3	1895.3	2591.0	2887.8
	SD	79.9	85.0	84.3	125.5
A-Weighted Energy** in joules/M^2	Mean	162.0	142.1	173.3	202.4
	SD	6.0	15.8	12.2	19.6
Number of Measurements		8	12	12	11

*Standard Deviation

**See Appendix A

TABLE 13

NUMBER OF ROUNDS ALLOWED BY THREE NATIONAL STANDARDS

		M4A2 Gauge Location				M119A2 Gauge Location				M203 Gauge Location			
		1	2	3	4	1	2	3	4	1	2	3	4
(United States of America)													
N_B**	Mean	46.3	74.4	43.4	42.1	5.6	16.5	8.2	5.3	1.2	1.5	1.6	.8
MIL-STD-1474B	SD*	11.8	17.2	14.0	14.2	1.7	4.3	2.4	1.4	.5	.3	.6	.3
Number of Measurements		12	12	12	12	12	12	12	12	6	12	12	12
(Federal Republic of Germany)													
N_C** 29 dB	Mean	15.1	19.6	17.4	15.4	5.0	7.4	6.8	5.3	3.9	4.2	5.3	4.2
Attenuation	SD*	1.3	3.3	1.6	2.2	.5	.4	.5	.8	.4	.5	.5	.5
Number of Measurements		12	12	12	12	12	12	12	12	5	11	11	11
(Netherlands)													
N_D** 29 dB	Mean	10.3	10.7	9.1	8.7	3.6	4.5	3.7	4.0	3.3	2.2	4.1	3.8
Attenuation	SD*	1.7	1.9	1.5	1.8	.6	.7	.9	.7	1.7	.8	2.7	1.7
Number of Measurements		12	12	12	12	12	12	12	12	6	12	12	12
(Federal Republic of Germany)													
N_C** 25 dB	Mean	6.0	7.8	6.9	6.1	2.0	2.9	2.7	2.1	1.6	1.7	2.1	1.7
Attenuation	SD*	.5	1.3	.6	.9	.2	.2	.2	.3	.2	.2	.2	.2
Number of Measurements		12	12	12	12	12	12	12	12	5	11	11	11
(Netherlands)													
N_D** 25 dB	Mean	4.1	4.2	3.6	3.5	1.4	1.8	1.5	1.6	1.3	.9	1.6	1.5
Attenuation	SD*	.7	.8	.6	.7	.3	.3	.3	.3	.7	.3	1.1	.7
Number of Measurements		12	12	12	12	12	12	12	12	6	12	12	12

*Standard Deviation

**See Appendix C

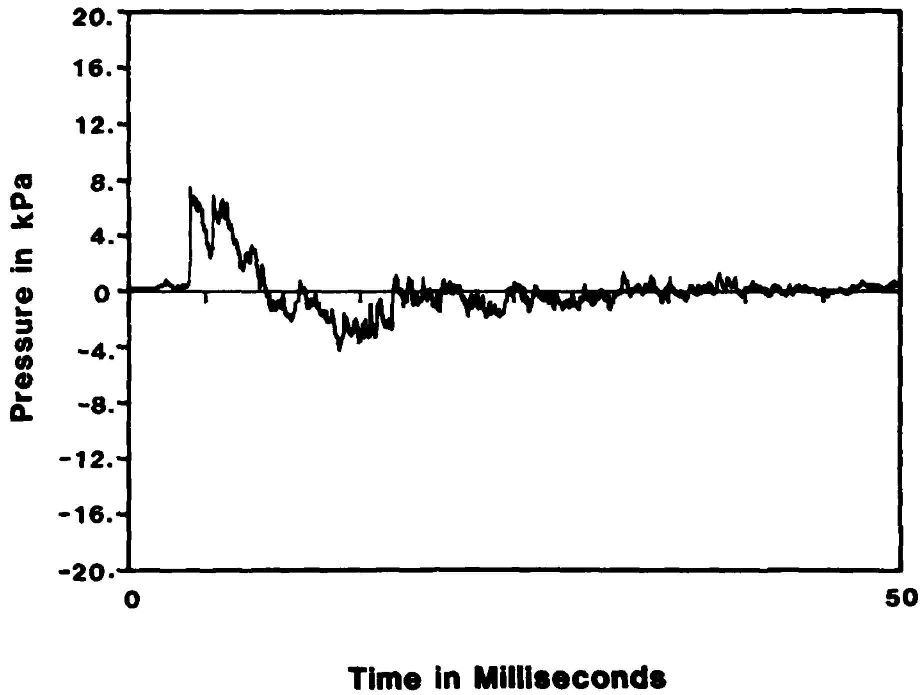

FIGURE 3. Pressure-time History Produced at Location 2 by Firing the M4A2 Propelling Charge.

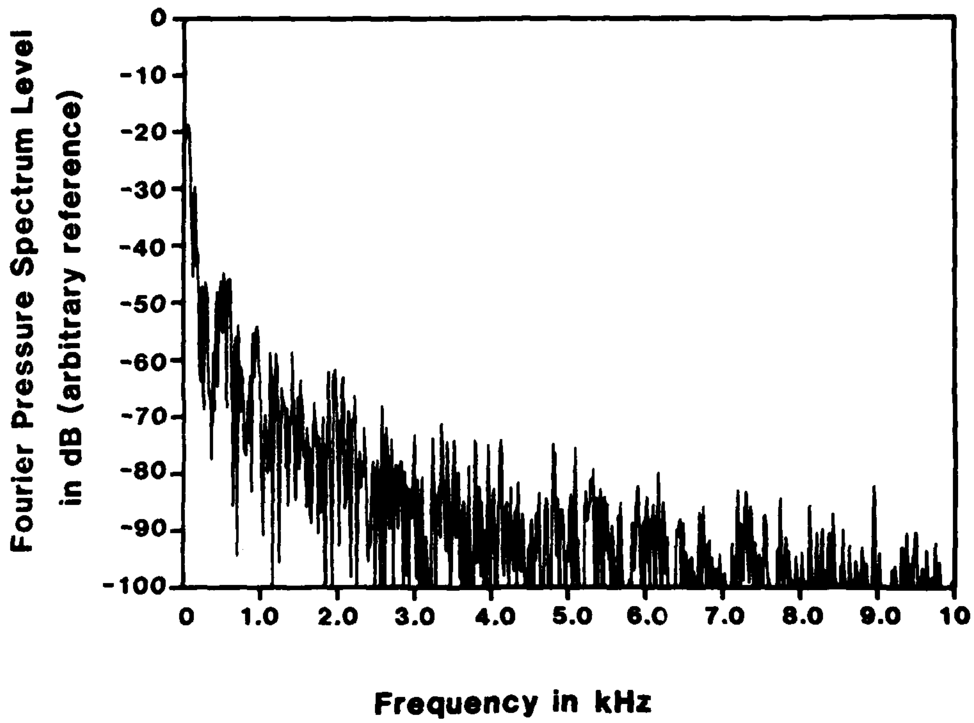

FIGURE 4. Fourier Pressure Spectrum of Impulse Produced at Location 2 by Firing the M4A2 Propelling Charge.

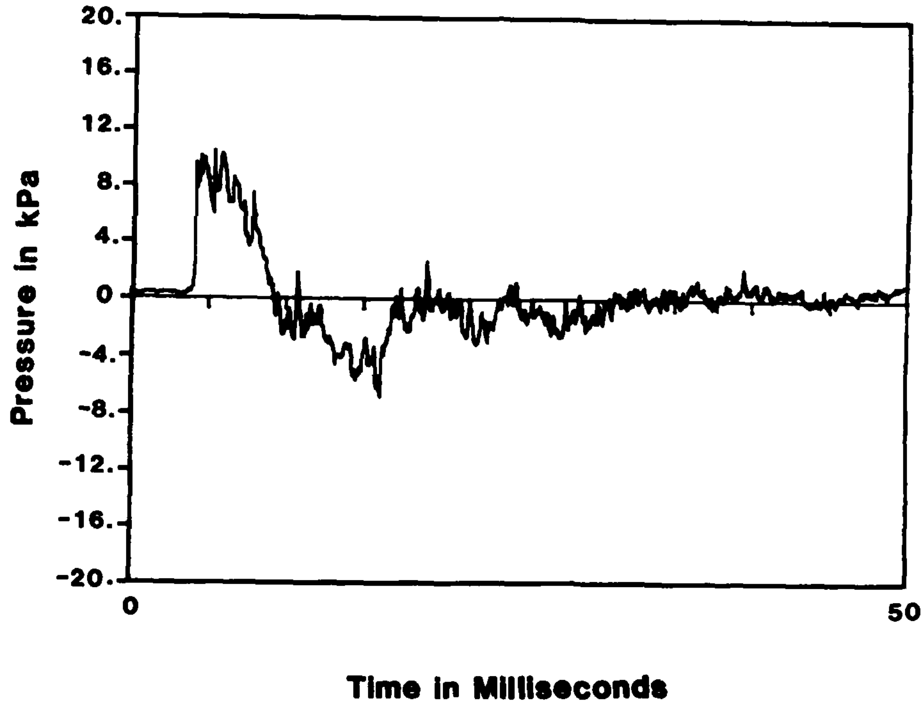

FIGURE 5. Pressure-time History Produced at Location 2 by Firing the M119A2 Propelling Charge.

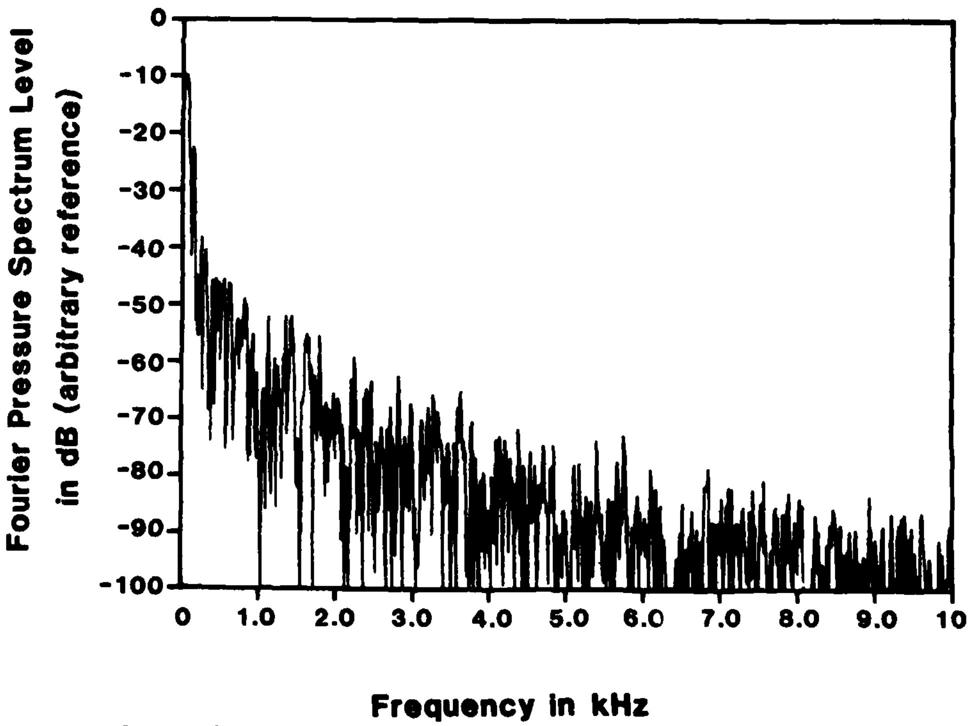

FIGURE 6. Fourier Pressure Spectrum of Impulse Produced at Location 2 by Firing the M119A2 Propelling Charge.

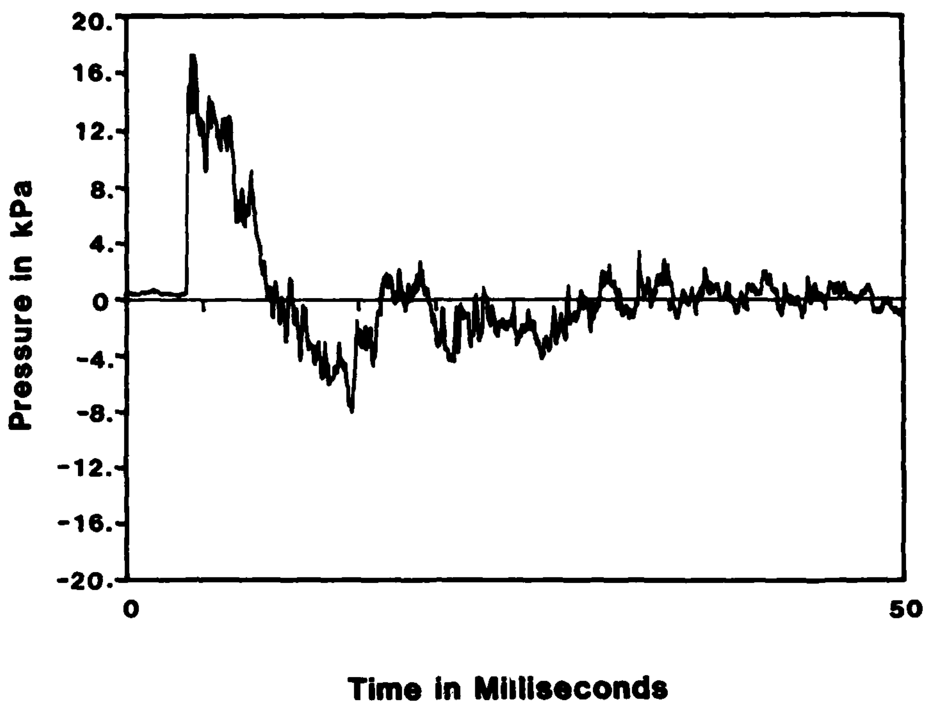

FIGURE 7. Pressure-time History Produced at Location 2 by Firing the M203 Propelling Charqe.

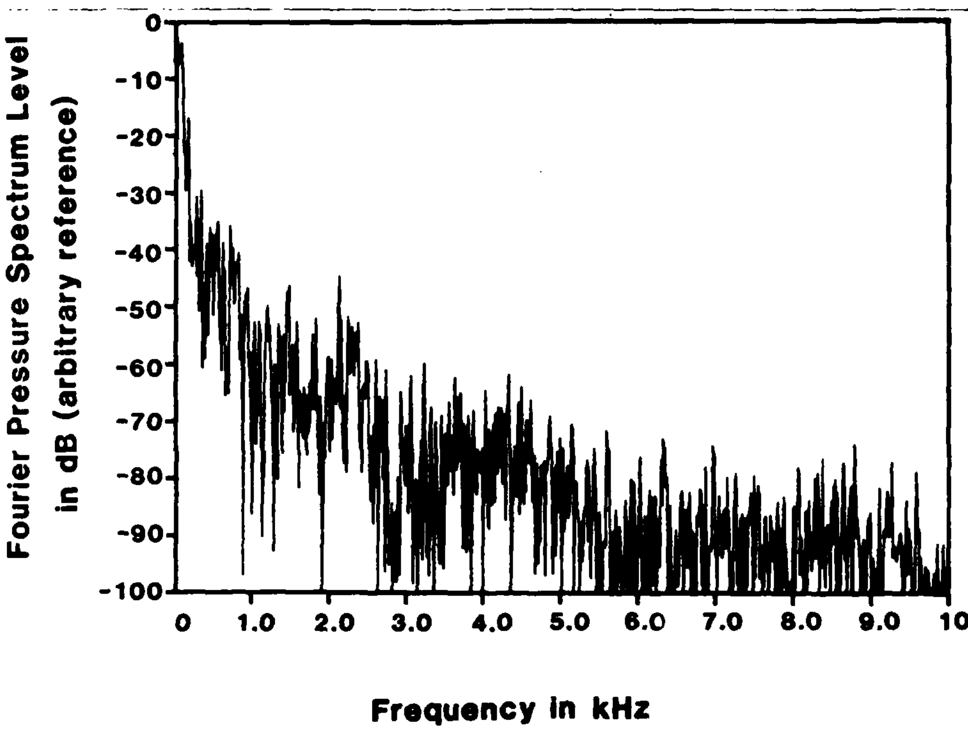

FIGURE 8. Fourier Pressure Spectrum of Impulse Produced at Location 2 by Firing the M203 Propelling Charge.

that the noise limits in Germany and the Netherlands would permit three to four times the number of M203 rounds as the US military standard when the hearing protection is assumed equal. The exact opposite is true for the M4A2. This difference is due to a fundamental difference in the way these standards trade peak pressure for allowable number of rounds. With only 25 dB of hearing protection, they allow a number of M203 rounds about equivalent to the US military standard and proportionately fewer of the M4A2 and M119. None of the standards would predict the 12 rounds of M203 to be an acceptable exposure.

The primary audiometric data for assessing the adequacy of the hearing protection were the TS measures obtained on the right ear during the time intervals 2-10 min postexposure. Table 14 contains the mean and standard deviations for TS in the right ear resulting from the three charges. This table also contains the 95th percentile and 95 percent confidence upper bound (see Appendix B) on the 95th percentile TS. Table 15 contains comparable data for the left ear. In all cases, the mean threshold shift is essentially zero and the 95th percentile TSs are small. The upper bounds on the 95th percentile indicate that with 95 percent confidence the 95th percentile threshold shift in the right ear is below the CHABA limits of Table 1 except for .5, 1 kHz for the M4A2, and 1 kHz for the M203. However, since the CHABA limit is only 10 dB at the lower frequencies and the range of measured TS appears to be about twice this value at all frequencies as a result of audiometric variability, the failure of the 95 percent confidence is bound to fall below the CHABA limit in that the lower frequencies is probably due to statistical variability. Figures 9, 10, and 11 show the distribution of TSs produced by the 12 rounds of M4A2, M119A2, and M203 charges, respectively, for the frequencies 2.0, 4.0, and 6.0 kHz. These are the frequencies we would expect to show the greatest effect. All of these distributions are symmetric around zero indicating that at the earliest test after the exposure there was no evidence of a TS of any significant magnitude. Figure 12 shows the mean TS for all frequencies along with an estimate of the 95th percentile TS and the 95 percent confidence bound on the 95 percent TS, immediately after exposure to the M203. Again, it is clear that there was no significant TS. That is, with 95 percent confidence, the results indicate that the 95th percentile TS resulting from exposure to 12 rounds of M203 is below the limits adopted by CHABA in its proposed damage risk criterion for impulse noise (1968).

To demonstrate that the histograms in Figures 9, 10, and 11 simply are reflective of audiometric variability, three preexposure audiograms were analyzed by using two of them to calculate a baseline and the third was used as a psuedopostexposure audiogram to calculate TS based on no exposure. These control TSs are shown in histogram form in Figure 13. Notice the shape and dispersion is similar to all of the histograms resulting from actual exposures. The general form of these distributions and the fact that the TS measure is a sum (or difference) of observed thresholds each with a random error component suggests these distributions should be approximately normally distributed with mean equal to zero and some variance which can be estimated from the standard deviation values in Table 14. The distributions of TS at 2.0, 4.0, and 6.0 kHz for all charges were analyzed using a chi-square test for goodness of fit of a normal distribution with mean zero

TABLE 14

STATISTICAL PARAMETERS OF THRESHOLD SHIFT MEASURED IN THE RIGHT EAR 3 TO 10 MINUTES AFTER EXPOSURE

	Test Frequencies in kHz						
	.5	1.0	2.0	3.0	4.0	6.0	8.0
M203							
Mean	-0.5	-0.2	1.0	-0.5	-0.4	-1.3	-0.7
Standard Deviation	5.1	4.1	4.4	4.1	3.4	5.0	5.2
95th Percentile	8	5	9	5	4	6	6
Upper Bound on 95th Percentile	9	13	10	5	10	10	10
M119A2							
Mean	-0.5	-0.6	0.1	-0.8	-0.3	0.0	-0.4
Standard Deviation	3.9	3.4	3.4	4.0	4.1	3.5	4.8
95th Percentile	5	5	5	5	4	4	7
Upper Bound on 95th Percentile	10	7	7	8	10	17	11
M4A2							
Mean	-0.2	0.1	0.1	-0.2	-0.6	-0.2	-1.2
Standard Deviation	3.7	3.5	4.1	4.2	3.5	4.1	5.8
95th Percentile	6	5	6	6	3	5	6
Upper Bound on 95th Percentile	11	13	8	12	8	10	14

TABLE 15

STATISTICAL PARAMETERS OF THRESHOLD SHIFT MEASURED IN THE LEFT EAR 10 TO 17 MINUTES AFTER EXPOSURE

	Test Frequencies in kHz						
	.5	1.0	2.0	3.0	4.0	6.0	8.0
M203							
Mean	-0.8	0.0	-0.2	0.1	-1.0	-0.5	0.1
Standard Deviation	5.2	4.3	4.2	4.9	4.6	4.8	5.3
95th Percentile	6	6	5	7	7	6	9
Upper Bound on 95th Percentile	8	10	11	15	15	8	12
M119A2							
Mean	-0.4	-0.3	0.0	-0.5	-1.3	-1.1	-0.6
Standard Deviation	4.9	6.6	6.4	5.3	6.0	7.2	5.6
95th Percentile	6	7	12	7	6	6	5
Upper Bound on 95th Percentile	12	19	18	9	17	11	12
M4A2							
Mean	-1.3	-1.0	-0.1	-1.4	-0.9	-1.0	-0.9
Standard Deviation	4.0	4.6	4.3	4.5	5.8	4.0	5.7
95th Percentile	4	6	5	4	5	6	5
Upper Bound on 95th Percentile	6	12	17	8	15	15	8

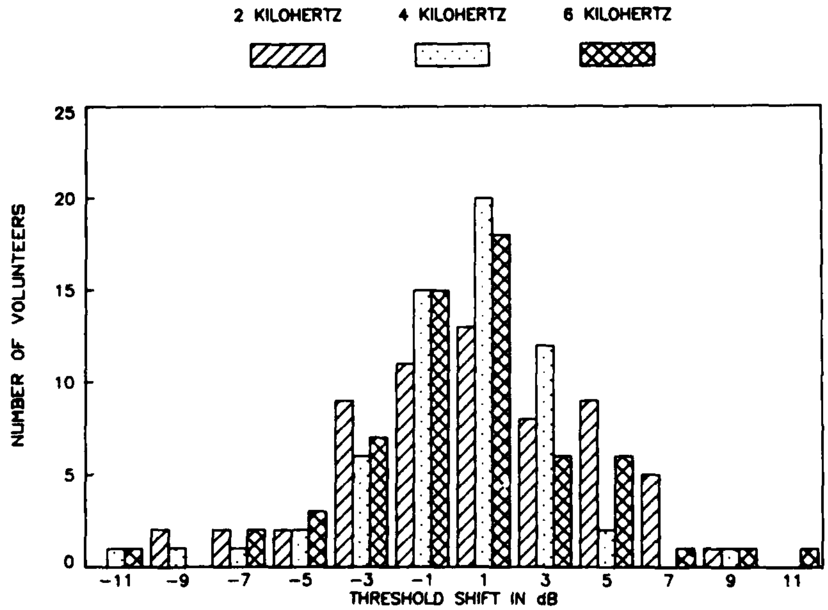

FIGURE 9. Distribution of Threshold Shifts Resulting from 12 Rounds of M4A2, Zone 7 at Audiometric Frequencies of 2.0, 4.0, and 6.0 kHz.

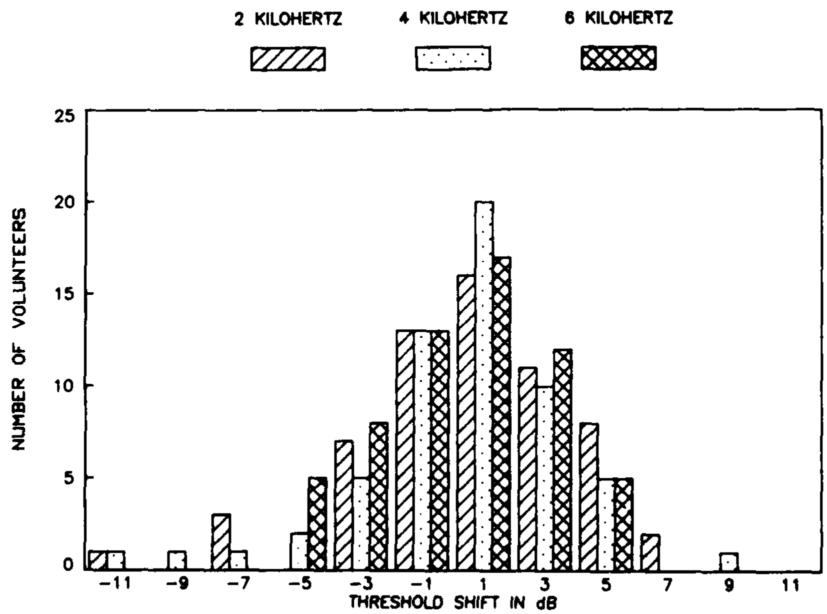

FIGURE 10. Distribution of Threshold Shifts Resulting from 12 Rounds of M119A2, Zone 8 at Audiometric Frequencies of 2.0, 4.0, and 6.0 kHz.

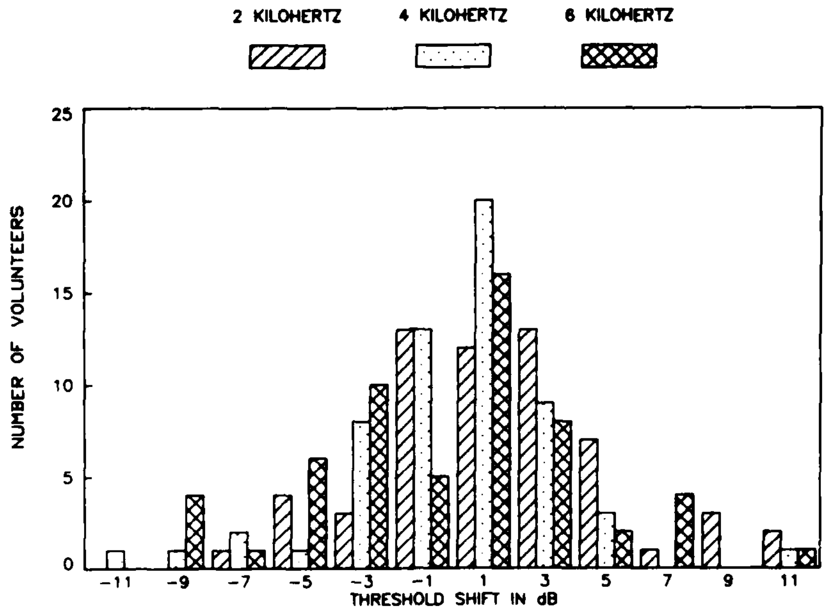

FIGURE 11. Distribution of Threshold Shifts Resulting from 12 Rounds of M203A2, Zone 8S at Audiometric Frequencies of 2.0, 4.0, and 6.0 kHz.

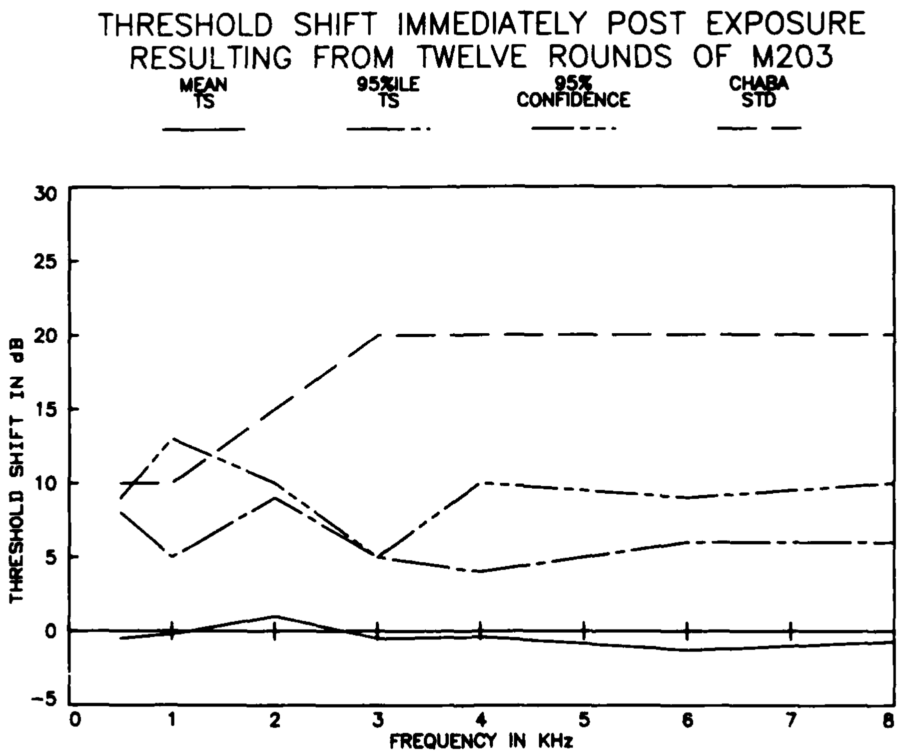

FIGURE 12. Mean Threshold Shift, 95th Percentile Shift and 95 Percent Confidence Bound on 95th Percentile Shift Compared to Limit from Table 1.

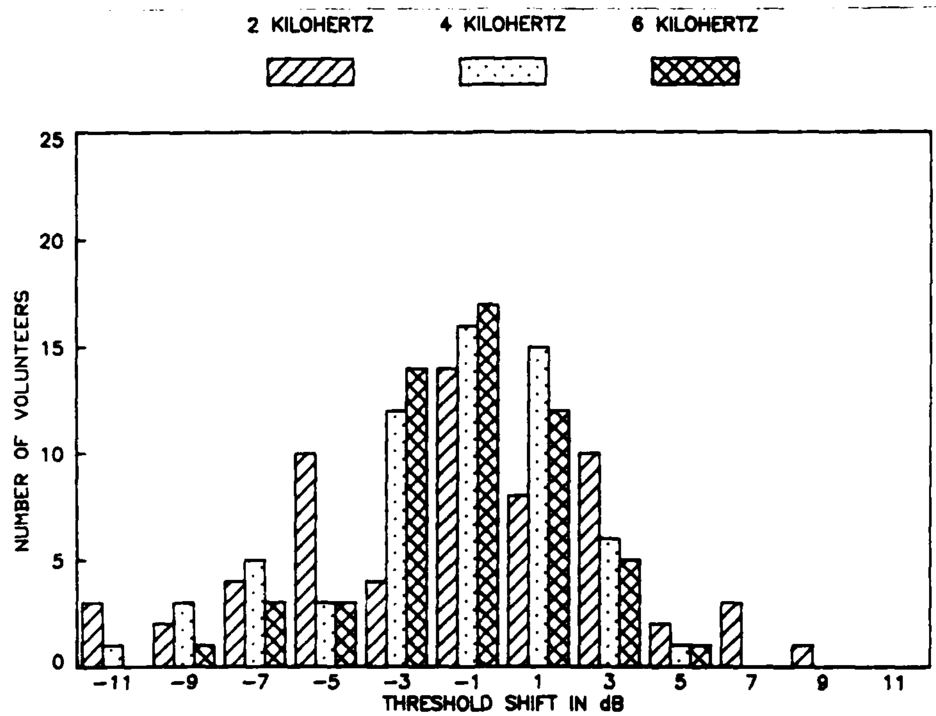

FIGURE 13. Distribution of TS at Three Frequencies Resulting from Audiometric Variability.

and standard deviation as in Table 14. None of the chi-squares was significant. This indicates no departure from normality with an assumed zero mean.

The results of the monitoring for nonauditory injury were negative. All laryngoscopic examinations were negative for petechiae or hemorrhages. All individuals who returned the stool guaiac tests for evaluation were negative. Postexposure roentgenograms showed no evidence of pneumothorax, expiratory, or other abnormality.

The results of this study provide a known reference point for the M203 charge with respect to the probability of TTS. This reference point establishes 12 rounds of M203 per day as an acceptable exposure. Table 16 contains the allowable number of rounds per day based on MIL-STD-1474B(MI) and the CHABA (1968) rule for trading number of rounds for level for each of the three propelling charges used in this study. Data from channels 2 and 3 are used as representatives of the exposure on each side of the weapon. Three alternative analyses, based on minimum, average, or maximum peak pressure, were used to bracket the number of rounds allowed under average and extreme conditions.

TABLE 16

ALLOWABLE NUMBER OF ROUNDS PER DAY BASED ON MIL-STD-1474B(MI)

Charge	Gauge Location	Min Peak	Average Peak	Max Peak
M203	2	2.9	1.5	0.37
	3	3.4	1.5	0.65
M119A2	2	19.6	10.9	5.3
	3	15.2	8.2	4.7
M4A2	2	99.9	52.4	18.9
	3	62.5	40.9	23.6

Using any of these analyses the M203 would be allowed less than 12 rounds per day. Since it has been shown empirically that at least 12 rounds should be allowed for the M203, this suggests that the allowable number of rounds based on current standards for the other charges should be adjusted upward. This can be done by computing the ratio of the validated 12 rounds for the M203 to the number of rounds allowed by current standards and using this scale factor to multiply the estimated number of rounds for the other charges. This is equivalent to an upward shift in the X, Y, and Z curves in MIL-STD-1474B(MI) for the M198. Table 17 gives the set of scale factors based on the three alternative peak values for the M203.

TABLE 17

SCALE FACTORS DERIVED FROM M203

	Min Peak	Average Peak	Max Peak
Position 2	4.1	8.0	32.4
Position 3	3.6	8.0	18.5

Since there are various ways to estimate the allowable number of rounds for each charge, a selection of which peak and duration to use is necessary. This decision is two-part. First, one of the six alternative scale factors (Table 17) must be selected for the M203 charge. Second, a choice of one of the three peak options and two channels (Table 16) must be made for the other two charges to provide the number of rounds to be multiplied. Thus, the three original options yield 36 possibilities for adjusted firing restrictions for both the M119A2 and the M4A2. The most conservative approach is to use the smaller M203, min peak multiplier from Table 17 and the lesser max peak number of rounds from Table 16. The least conservative approach would use the larger M203, max peak multiplier from Table 17 and the larger min peak number of rounds from Table 16. Other options fall between these extremes. The number of options possible is too great for detailed analysis here. Four options which provide a balance between being overly restrictive and overly risky are:

a. Option 1: The lesser of the min peak multipliers, 3.6, with the lesser of the max peak number of rounds for the other charges.

b. Option 2: The lesser of the average peak multipliers, 8, with the lesser of the max peak number of rounds for the other charges.

c. Option 3. The lesser of the min peak multipliers, 3.6, with the lesser of the average peak number of rounds for the other charges.

d. Option 4: The lesser of the average peak multipliers, 8, with the lesser of the average peak number of rounds for the other charges.

Table 18 gives the adjusted allowable number of rounds (firing restrictions) for these four options for the M119A2 and M4A2 charges. Clearly, there is little difference between options 2 and 3.

TABLE 18

ADJUSTED ALLOWABLE NUMBER OF ROUNDS PER DAY

	Option 1	Option 2	Option 3	Option 4
M119A2	14	32	29	65
M4A2	64	144	147	327

Field implementation of firing restrictions will require a method for determining allowable exposures when a firing day includes some combination of different charges. This can be done on a proportional "dose" basis by assigning each charge a "point value." These point values are computed by dividing the number of rounds in Table 18 into 1000 and adjusting so the number of rounds permitted of each charge is at or below the value in Table 18. For field use, any combination of the three charges could be used as long as the total accumulated "points" remain below 1000 (a full "dose"). Table 19 gives point values for all three charges.

TABLE 19

RECOMMENDED POINT VALUES

	Option 1	Option 2	Option 3	Option 4
M203	83	83	83	83
M119A2	72	32	35	16
M4A2	16	7	7	3

CONCLUSIONS

Properly inserted E-A-R earplugs provide adequate hearing protection for personnel firing the M198 12 rounds of M203, Zone 8S. This conclusion depends heavily on the condition that these plugs are properly inserted. Improper insertion of the earplugs could reverse the finding that they afford adequate protection. There is no evidence there is any effect on hearing from this exposure. In addition, there is no evidence for laryngeal, gastro-intestinal, or pulmonary injury from this exposure.

MIL-STD-1474B(MI) provides a conservative noise limit for the M198, 155mm howitzer. While an exact upper limit on safe exposure to the M198 was not determined, this limit is clearly greater than that contained in MIL-STD-1474B(MI).

RECOMMENDATIONS

It is recommended that firing the M203 charge with the M198 be permitted up to 12 rounds per day when crewmembers wear properly inserted yellow foam earplugs (NSN: 6515-00-137-6345). When firing different charges during the same 24-hour period, a reasonably conservative limit on the total number of rounds can be calculated by using the point system from option z, Table 19. Each round is assigned points according to the type of charge used. The total number of points for all rounds must be kept below 1000. This procedure is only valid when properly inserted yellow foam earplugs are worn.

Since these recommended limits on number of rounds depend critically on the proper wearing of the earplugs, a training program should be instituted so every soldier likely to be near the M198 during firing can accomplish a proper insertion of the foam earplugs.

The conclusions of this study are specific to the M198, 155mm-towed howitzer. They do not constitute a basis for revising current military standards or devising new damage risk criteria. The results of this study are not applicable to artillery systems in general or to other types of weapons systems because the study was designed to answer specific questions about the M198/M203. Generalization of these findings should be limited to weapons which produce a pressure-time history similar to that of the M198.

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APPENDIX A

FORMULA FOR COMPUTATION OF ENERGY LEVELS OF THE IMPULSE EXPOSURE

The following equation was used to calculate the energy transported with an impulse per unit of area.

$$W = \frac{1}{\rho c} \int_{-\infty}^{\infty} p^2(t)\, dt \tag{1}$$

The following definitions apply:

W is energy per unit area transported in the specified direction (joules/ M^2.)

p(t) is the instantaneous pressure as a function of time (Pa)

ρc is the specific acoustic impedance taken as 417 rayls (N.Sec/M^3) for air

This equation is subject to the assumption that the impulse measured in the far field is a plane wave. It should be noted that the pressure measurements were made without the subject in position but at a point in space approximating the entrance to the subject's ear canal during the exposures. Equation (1) then was approximated by digital integration of a time series representing p(t) for a single impulse. This value then was converted to a level by

$$L\varepsilon = 10 \log W/Wo \tag{2}$$

where Wo was taken to be 1 joule/M^2. The A-weighted energy was computed by using Parseval's identity:

$$E = \int_{-\infty}^{\infty} p^2(t)dt = \frac{1}{2\Pi} \int_{-\infty}^{\infty} |F(\omega)|^2 dw \tag{3}$$

where $F(\omega)$ is the Fourier transform of p(t). We then applied an A-weighting function $|A(\omega)|^2$ to $|F(\omega)|^2$ and combined equation (3) with equation (1), to obtain the A-weighted energy WA by

$$WA = \frac{1}{2\Pi\rho c} \int_{-\infty}^{\infty} |A(\omega)|^2 \; |F(\omega)|^2 \, dw \tag{4}$$

In practice $|A(\omega)|^2$ can be estimated as the squared magnitude of the transfer function of an A-weighting filter which conforms to ANSI S1.4-1971(R1976) Specifications for Sound Level Meters, Type I.

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APPENDIX B

STATISTICAL FORMULAS

The following procedures and equations can be used for estimating confidence intervals about a percentile cut of a random variable with a continuous probability density function:

1. Assume a random sample of size n, $x_1, x_2 \ldots x_n$ of a random variable X with probability density function f(x) and cumulative distribution function $F(z)=\int^z f(x)dx$. Further assume that for any positive fraction p between 0 and 1 the equation $F(z)=p$ has a unique solution z_p such that $F(z_p)=p$.

2. If we form the order statistic Y such that y_1, is the smallest X_i and y_2 the next smallest and so on until y_n is the largest x_i, the probability that $y_i < z_p$ given by $Pr(y_i < z_p) =$

$$\sum_{w=i}^{n} \frac{n!}{w!(n-w)!} p^w(1-p)^{(n-w)}$$

This is simply the upper "tail" of the binomial distribution with parameters n and p.

3. The 100p percentile cut z_p is bounded by $y_i < z_p < y_j$, $i<j$ with probability $Pr(y_i < z_p < y_j) = Pr(y_i < z_p) - Pr(y_j < z_p)^p =$

$$\sum_{W=i}^{j-1} \frac{n!}{w!\ (n-w)!} p^w(1-p)^{(n-w)}$$

4. By judicious selection of i, j, and n, the 100r percent confidence interval for z_p can be estimated for any positive fraction r between 0 and 1 by taking the order statistics y_i and y_j (the ith highest and the jth highest observation on X) so that $Pr(y_i < z_p < y_j) = 4$.

5. For 60 subjects the 95th percentile TTS is greater than the 55th highest TTS with probability .92 and less than the highest TTS with probability .95. These two scores (the 55th and 60th highest) give the approximate symmetric 90 percent confidence interval for statistical tests.

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APPENDIX C

EQUATIONS FOR NUMBER OF ROUNDS

The following is derived from Pfander, Bongartz, and Brinkmann (1975) and Pfander et al., 1980.

$$N_C = 10 ** .1*(164.6 - Lp + AT - 10*\log C)$$

where:

Lp is peak pressure in dB SPL

AT is assumed attenuation in dB

C is duration (Pfander, Bongartz, and Brinkmann, 1975) in msec

N_C is allowable number of rounds

The following equation is derived from Smoorenburg (1982)

$$N_D = 10 ** .1*(166.2 - Lp + AT - 10*\log D)$$

where:

Lp is peak pressure in dB SPL

AT is assumed attenuation in dB

D is duration (Smoorenburg, 1982) in msec

N_D is allowable number of rounds

The following equation is derived from MIL-STD-1474B(MI)

$$N_B = 100 * 10**.2*(167 - Lp + (2/\log 2)*(\log 200/B)$$

where:

Lp is peak pressure in dB SPL

B is duration (MIL-STD-1474B(MI) in msec

N_B is allowable number of rounds

(Attenuation is assumed to be 29 dB)

APPENDIX D

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